Meteorological Aspects of White Pine Blister Rust in Colorado and Wyoming

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Meteorological Aspects of White Pine Blister Rust in Colorado and Wyoming

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Abstract

Cronartium ribicola (J.C. Fisch.) is the causal agent for the exotic fungal disease known as white pine blister rust (WPBR). White pine blister rust infection occurs when compatible interactions between susceptible hosts (five needle pines and *Ribes* species), the pathogen (*C. ribicola*) and conducive environmental conditions occur. Favorable conditions of temperature and moisture must accompany an adequate amount of spores and susceptible hosts. The occurrence of these conditions in currently infested areas of Wyoming and uninfested areas of Colorado is not known. We determined the relationship between long term, regional meteorological data sources and local meteorological data stations placed directly in white pine limber stands throughout Colorado and Wyoming. Most local stations had on average cooler temperatures, higher relative humidity and more suitable infection periods. Most correlations between regional and local stations were sufficient to utilize the long term data to predict what conditions would occur in the limber pine stands. Regression relationships will be developed so corrected values can be used for longterm station data. Significant differences in meteorological conditions occur between sites within Colorado and Wyoming. Suitable meteorological conditions occur more frequently and for longer periods of time in Colorado than in Wyoming where rust incidence ranges from 10-35%. Thus, the conditions for white pine blister rust infection to occur is more frequent and for longer periods of time in Colorado than Wyoming. Thus, the risk of blister rust damage to Colorado five needle pines is greater based on meteorological conditions. Future work will determine if meteorological data can explain the severity of damage from blister rust in infested areas of Wyoming.

Introduction

Cronartium ribicola (J.C. Fisch.) is the causal agent for the exotic fungal disease known as white pine blister rust (WPBR). The disease occurs when there are compatible interactions between susceptible hosts, virulent pathogens, and conducive environmental conditions (Kearns 2005). Favorable conditions of temperature and moisture must accompany an adequate amount of spores and susceptible hosts.

Environmental factors determine disease severity and incidence in areas where both the pathogen, *Cronartium ribicola*, and hosts, five needle pines and *Ribes* species, are present (Weltzien 1988). The development of plant fungal disease is controlled by three factors: the abundance of inoculum, the environment during infection, and the disease development as modified by plant defenses (Talley *et al* 2002). In eastern states, climate largely determines the distribution of white pine blister rust (Van Arsdel 1965). Climate is often the driving abiotic factor in determining disease incidence and severity (Weltzien 1988). Production and germination of the various spore stages of *C. ribicola* are affected by temperature, moisture, and time, and may also vary due to genetic and environmental conditions (Table 1). Pine trees can escape white pine blister rust for one of two reasons, either they are genetically resistant to the rust or they grow in an unfavorable climate for rust infection to occur (Van Arsdel 1965).

The life cycle of *Cronartium ribicola* is complex and depends on various meteorological conditions for completion. The cycle involves five spore stages and two hosts. The primary hosts are five needle pines and the alternate hosts are various species of *Ribes* (Kendrick 2000, Kearns 2005, see Table 1). The dissemination and reproduction of pathogenic fungi largely

depends upon favorable environmental conditions (Hirt 1935). The five spore stages of white pine blister rust have specific temperature and moisture conditions necessary for production and germination (Table 1) (Van Arsdel et al. 1956).

Table 1. Environmental conditions that promote *Cronartium ribicola* spore stages.

Spore Stage	Season	Host	Temperature Requirements		Humidity Requirements	Sources	Comments
pycniospores	Typically one season prior to aecia Spring or fall	White pines	Warm temperatures			Lachmund 1933, Meilke 1943	Produced in gelatinous droplets
aeciospores	Early summer, spring	Produced on white pines, dispersed to *Ribes*	**Production** 16-28 °C	**Germination** 8° to 24°C	Saturated air, free moisture	Van Arsdel *et al.* 1956	
urediniospores	summer	Ribes	**Production** Daytime: 16-28°C Nighttime: 2-20°C	**Germination** 16-28°C Optimal germination occurs at 20°C	Optimal germination requires free water	Van Arsdel *et al.* 1956	Whether a urediniospore produces uredia or telia depends largely on temperature
teliospores	late summer	*Ribes*	Germination: 2 to 21°C Rate of germination varies		Wet periods	McDonald et al. 1981, Van Arsdel *et al.* 1956	Teliospores germinate and produce basidia= basidiospores
basidiospores	late summer	Produced on *Ribes,* dispersed to white pines	**Ribes** Production: 2 to 21°C Optimal: 10-18°C	**Pines** 0.5-1 to 28°C	Free water or relative humidity >97% for germination	Hirt 1942, Bega 1960, Van Arsdel *et al.* 1956	

Predicting the rust hazard of white pine blister rust is dependent on various tree, pathogen and environmental factors. Hazard can be described in two ways, by incidence and by severity (Kearns 2005). Incidence is defined as the proportion of trees infected and severity is defined as the amount of disease on the host (Kearns 2005). The severity of white pine blister rust is defined by the number of branch and stem cankers per tree (Kearns 2005). The environmental conditions and occurrence of the conditions that can predict past, current and future white pine blister rust hazard and severity are not known in Colorado and Wyoming. Thus, the overall goal of this research was to utilize on site meteorological data to determine if rust occurrence can be predicted. The specific objectives of this research were to: (1) determine if long term, regional meteorological data sources have comparable data with temporary meteorological stations placed in white pine stands, (2) determine if differences in meteorological conditions occur among white pine blister rust study sites in Colorado and Wyoming.

Methods and Materials

Meteorological Data Sources

The meteorological data sources used in our analysis included Remote Automated Weather Stations, Onset HOBO® Weather Station Pro Data Loggers, and Wyoming Department of Transportation atmospheric sensors (Table 2).

There are nearly 2,200 interagency Remote Automated Weather Stations (RAWS) strategically located throughout the United States. A total of 12 RAWS in Wyoming (5-12 years of usable

data) and 9 RAWS in Colorado (10-15 years of usable data) were used in this research. Observations for RAWS included one-hour precipitation intervals, relative humidity, air temperature, wind speed and direction, and barometric pressure.

RAWS units collect, store, and forward data to a computer system at the National Interagency Fire Center (NIFC) in Boise, Idaho via the Geostationary Operational Environmental Satellite (GOES). The GOES is operated by the National Oceanic and Atmospheric Administration (NOAA). These data are automatically forwarded to several other computer systems including the Weather Information Management System (WIMS) and the Western Regional Climate Center in Reno, Nevada (www.wrcc.dri.edu).

The four Wyoming Department of Transportation (WYDOT) atmospheric sensors were located close to highways and in open areas of Wyoming. Observations of these stations included 15-minute precipitation intervals, relative humidity, air temperature, wind speed and direction, and dewpoint.

Onset HOBO® Weather Station Pro Data Loggers were placed in white pine stands throughout Wyoming (25) and Colorado (26) which have collected, on average, four to five years of continuous meteorological data. HOBO data logger data included half hour intervals of relative humidity, air temperature and dewpoint. Some HOBO stations were removed from one location and moved to another so there are fewer data for some locations.

Table 2. Meteorological data sources.

Meteorological Source	Years of Data	Number of Stations	Environment
Remote Automated Weather Stations	WY: 5-10 years CO: 10-15 years	WY: 12 CO: 9	Open areas, valleys, low elevation hilltops
Wyoming Department of Transportation	9-10 years	WY: 4	Open areas, in vicinity of highways
HOBO Weather Station Loggers (CSU)	3-4 years	WY: 25 CO:26	Stations placed directly in limber pine stands

Meteorological Variables and Restrictions on Data

A suitable infection period was considered to be a time period where temperature and humidity conditions for rust occurred for at least 6 hrs (25%) or 12 hrs (50%) of hours in that day (Table 3). The data were first downloaded into Microsoft Excel (Microsoft Office 2003) and cleaned to remove repeated data or extreme outliers. Data were then filtered using Statistical Analysis Software Version 9.1 (SAS Institute, Inc. 2002-2003) and restricted to generate the variables used in this analysis (Table 3). The initial filtering process was conducted to restrict the analysis to days where at least 14 hours were present with relevant humidity and temperature data. In order to narrow down suitable infection periods for white pine blister rust on *Ribes* species and five needle pines, the data were restricted to the temperature, relative humidity, and time factors

believed to allow infection to occur (Table 1). More filter options chosen to run on the meteorological data collected were as follows:

- Time restricted to the months of May 1-Sept 30
- Relative Humidity exceeded 90%
- Temperature restrictions between 0 to 23.9°C (32° and 75°F) for May 1- Sept 30
- Temperature restrictions between 21.1 and 27.8°C (70° and 82°F) for May 1-June 30 ("spring" months) in addition to the above temperature requirements through September.

There are no spring and fall results presented in this report but future work will contain this information.

Average values for mean min, max and average daily temperature, relative humidity (RH), and mean monthly average percentage of hours in a day where relative humidity exceeded 90% were compared between long term stations (RAWS and WYDOT) and HOBOS placed under limber pine trees near (1-15 km) the long term stations.

Meteorological variables (Table 3) were used to describe average meteorological conditions at each WPBR Study Site by year and month and to calculate pressure index (hazard ratings) for each site. Pearson Correlation Coefficients between HOBO and long-term stations for these variables were calculated to predict the compatibility of long term data sources and stations placed directly into white pine stands.

Table 3. Meteorological variables used for white pine blister rust risk assessment.

Variable	Description
Minimum temperature	Minimum monthly average temperature
Maximum temperature	Maximum monthly average temperature
Mean temperature	Mean monthly average temperature
Change in temperature	Monthly average change in temperature
Mean relative humidity	Mean monthly average relative humidity
Mean exceed 90	Monthly average percentage of hours in a day where relative humidity exceeded 90%.
Suitable Period >50% of Day (A suitable infection period variable)	If mean relative humidity exceeded 90% for at least one half of the hours in a day, that day was given a value of 100. If it did not exceed 90% for half of the hours, it was given a 0. This variable explained the percentage of days in a month that had more than 50% of hours exceeding 90% relative humidity (within the temperature requirements).
Suitable Period >25% of Day (A suitable infection period variable)	If mean relative humidity exceeded 90% for at least one quarter of the hours in a day, that day was given a value of 100. If it did not exceed 90% for one quarter of the hours, it was given a 0. This variable explained the percentage of days in a month, which had more than 25% of hours exceeding 90% relative humidity (within the temperature requirements).

Objective 1: Determine if long term, regional meteorological data sources have comparable data with temporary meteorological stations placed in white pine stands.

HOBO vs RAWS and WYDOT Stations:

Mean Meteorological Values:

Mean values of temperature, relative humidity, and related values from RAWS and WYDOT stations were variable in how they corresponded to nearby HOBO stations placed in limber pine stands. In some study sites the mean values were not significantly different but in others there were large differences with the HOBO site having much higher RH (Table 4). In general the hobo stations recorded higher relative humidity and more importantly, more potential infection episodes. However, there is considerable variation in the data so even though there were 5-10% differences in the percentage of days with 25 or 50% suitable periods between the long term stations and Hobos the differences were not significantly different (Tables 5 and 6). Future regression analysis will provide corrected values for the long term RAWS and WYDOT station data and thus more realistic meteorological values for the research sites. We will then relate disease incidence and infection pressure values.

Table 5. Mean values for RAWS, WDOT and HOBO meteorological stations: WY.

Wyoming Stations					Average Values[1]			
National Forest/Region	WPBR Study Area	Station Name	HOBO Dates	N	Mean Temp	Mean RH	>50% hours suitable	>25% hours suitable
Medicine Bow National Forest	Sierra Madres	Cow Creek Raws						
		Sierra Madre North Hobo	2004-2006					
		Sierra Madre South Hobo	2004-2006					
	Laramie Peak East/South	EsterBrook RAWS			61.1b	49.8a	5.9a	13.1a
		Ester Brook Road South Hobo	2001-2005	11	55.9a	53.8a	8.0a	5.9 a
		Ester Brook Road North Hobo	2001-2005	11	58.9a	50.1a	4.6a	12.4a
	Laramie Peak West	Casper Mountain RAWS						
	Medicine Bow Mountain Range Northease	Arlington WYDOT	1994-2002					
		Centennial Ridge Hobo	2004-2006					
		Arlington Hobo	2004-2006					
	Medicine Bow Mountain Range Southeast	Sawmill Park RAWS	1988-2003					
		Centennial Ridge Hobo	2004-2006					
	Pole Mountain	Vedauwoo WYDOT	1994-2002		55.0e	48.2a	7.1a	15.5a
		Pumpkin Vine WYDOT	1994-2002		51.2	44.4	2.3	8.9
		Vedauwoo West Hobo	2001-2006	4	52.7c	47.3a	11.3a	20.0a
		Vedauwoo East Hobo	2001-2004	4	54.2d	48.8a	10.1a	17.7a
		Pilot Hill North Hobo	2001-2006	4	51.4a	49.1a	12.8a	19.0a
		Pilot Hill South Hobo	2001-2006	4	52.0b	48.2a	11.0a	18.1a
Bureau of Land	Shirley Mountains	Pathfinder Hill WYDOT	1994-2002					

Management		Shirley North Hobo	2004-2006					
		Shirley South Hobo	2004-2006					
	Green Mountains	Camp Creek RAWS	1997-2004					
		Green Mountains Hobo	2005-2006					
Shoshone National Forest	Dubois	Elk Horn RAWS			53.9	42.1	0.3	4.1
		Horse Creek FR 285 Hobo	2001-2006	11	53.5	46.2	3.1	10.8
		Horse Creek Valley Hobo	2001-2006					
		Wind River Lake Hobo	2001-2006					
	Cody	Crandall RAWS	1994-2003	12				
		Dead Indian Overlook Hobo	2001-2006	11				
		Chief Joseph Hwy East Hobo	2001-200?	12				
Wind River Reservation	Wind River Reservation	Wind River RAWS						
		Wind River Hobo	2004-2006					
Bighorn National Forest	Shell Creek / Mill Creek (1989-2003)							
	Burgess Junction	Burgess Junction RAWS						
	Buffalo	School House RAWS						
		Middle Fork Campground Hobo	2002-2004	6				
	Ten Sleep Canyon	RAWS						
		MiddleTensleepCanyon Hobo	2001-2003					
		LowerTensleepCanyon Hobo	2001-2005					
		UpperTensleepCanyon Hobo	2001-2005					

[1] Average values followed by similar letter are not significantly different at P=0.05, based on LSD. Blank cells indicate currently missing values but this data will be utilized in future analysis

Table 6. Mean values for RAWS, WDOT and HOBO meteorological stations: CO.

Colorado Stations				Average Values				
National Forest/Region	WPBR Study Area	Station	HOBO Dates	N	Mean Temp	*Mean RH	>50% hours suitable	>25% hours suitable
Roosevelt National Forest	Northern Front Range	Red Feather RAWS			57.2d	44.6a	3.6a	12.3a
		Cherokee Park Hobo	2001-2005	10	55.9b	53.0b	11.7b	24.1b
		Sheep Creek Hobo	2001-2005	10				
		Prairie Divide Hobo	2001-2005	10	57.1c	50.4a	7.6a	16.2a
		Crystal Lakes Hobo	2001-2005	10	54.2a	51.2a	7.0a	17.7a
San Isabel National Forest	Upper Arkansas	Red Deer RAWS			58.3e	38.1a	1.6a	5.8a
		Taylor Gluch RAWS			52	47.2	12.4	27.2
		Bald Mt Hobo	2001-2005	10	54.1d	46.5b	4.7a	11.4b
		Mount Princeton Hobo	2001-2005	10	50.2b	49.8b	6.2a	13.2b
		Mount Massive Lakes Hobo	2001-2005	10	50.3b	52.0b	10.8b	20.3c

		Lost Canyon Road Hobo.	2001-2005	10	47.0a	50.4b	5.9a	13.3b
		Garfield Hobo	2001-2005	10	52.2c	50.8b	6.5b	18.2b
Pike National Forest	South Park	Lake George RAWS			56.9d	50.0a	3.6a	19.2a
		Soda Creek RAWS			50.92	48.79	5.69	17.27
		Bailey RAWS			60.77	43.08	3.21	10.1
		Michigan Hill/Jefferson Hobo	2001-2005	10	49.0a	56.7b	12.9b	27.7b
		RedHill Pass Hobo	2001-2005	10	51.5b	51.1a	9.3a	18.9a
		Fourmile Creek/Fairplay Hobo	2001-2005	10	48.2a	55.4a	12.3b	27.4b
		Dicks Peak Hobo	2002-2005	7	51.3b	49.9a	9.5a	24.3a
		Currant Creek Pass Hobo	2002-2005	7	53.2c	47.5a	8.1a	17.0a
Rio Grande National Forest	Rio Grande	Blue Park RAWS			50.2b	47.3a	4.9a	21.5b
		Upper Agua Ramone Hobo	2001-2005	10	52.3c	49.1a	8.8a	17.0ab
		Lower Agua Ramone Hobo	2001-2005	10	54.7e	43.8a	2.3a	7.9a
		Demi John Peak Hobo	2001-2005	10	53.5d	49.5a	12.5b	19.3b
		Bennet Peak Hobo	2001-2005	10	46.5a	56.9b	13.7b	24.4b
San Isabel National Forest	Wet Mountains	Willis Creek RAWS						
		Wet Mts One Hobo	2005-2006					
		Wet Mts Two Hobo	2005-2006					
	Mosca Pass	Willis Creek RAWS						
		East Mosca Pass Hobo	2004-2005					
		North Mosca Pass Hobo	2004-2005					
		Mosca Pass Hobo	2004-2005					
		FS East Mosca Hobo	2004-2005					
		FS West Mosca Hobo	2004-2005					
		Medano Pass Hobo	2004-2005					

[1] Average values followed by similar letter are not significantly different at P=0.05, based on LSD. Blank cells indicate currently missing values but this data will be utilized in future analysis

Correlation Analysis:

Pearson correlations coefficients of mean temperature, relative humidity, >50% and >25% of a day between HOBO stations (local, shorter term meteorological data) and long term, regional meteorological stations were compared using infection period (growing season) months during the years 2001-2003. The number of months with available data to compare (N) are listed in Table 7 and Table 8 for Wyoming and Colorado, respectively.

Table 7. Wyoming Meteorological Data Sources and Pearson Correlation Coefficients

							Pearson Correlation Coeffici		
National Forest/Region	WPBR Study Area	RAWS	WYDOT Stations	HOBO Station Name	HOBO Dates	N	Mean Temp	*Mean RH	>50% hours suitable
Medicine Bow National Forest	Sierra Madres	Cow Creek		Sierra Madre North	2004-2006				
				Sierra Madre South	2004-2006				

	Laramie Peak East/South	Ester Brook (1989-2003)		Ester Brook Road South	2001-2005	11	0.99	0.92	0.67	0.66
				Ester Brook Road North	2001-2005	11	0.99	0.95	0.63	0.82
	Laramie Peak West	Casper Mountain (1995-2003)								
	Medicine Bow Mountain Range North		Skyline (1997-1998)							
			Arlington (1994-2002)	Centennial Ridge	2004-2006					
				Arlington	2004-2006					
	Medicine Bow Mountain Range Southeast	Sawmill Park (1988-2003)		Centennial Ridge	2004-2006					
	Pole Mountain		Vedauwoo (1994-2002)	Vedauwoo West	2001-2006	8	0.98	0.85	0.68	0.16
				Vedauwoo East	2001-2004	4	0.99	0.94	0.84	0.7
				Pilot Hill North	2001-2006	8	0.99	0.95	0.8	0.9
				Pilot Hill South	2001-2006	8	0.99	0.95	0.83	0.93
			Pumpkin Vine (1994-2002)	Vedauwoo West	2001-2006	4	0.75	0.8	0.83	0.49
				Vedauwoo East	2001-2004	4	0.78	0.97	0.77	0.78
				Pilot Hill North	2001-2006	4	0.82	0.99	0.95	0.95
				Pilot Hill South	2001-2006	4	0.83	0.99	0.5	0.96
Bureau of Land Management	**Shirley Mountains**		Pathfinder Hill (1994-2002)	Shirley North	2004-2006					
				Shirley South	2004-2006					
	Green Mountains	Camp Creek (1997-2003)		Green Mountain	2004-2006					
Shoshone National Forest	**Dubois**	Elkhorn (1990-2003, no 1997)		Horse Creek Basin. FR 285	2001-2006	11	0.99	0.82	0.89	0.74
				Horse Creek Valley	2001-2006					
				Wind River Picnic Area	2001-2006					
	Cody	Crandall (1994-2003)		Dead Indian Overlook	2001-2006	11	0.99	0.91	-	-
				Chief Joseph Hwy East	2001-2003	12	0.99	0.91	-	-
Wind River Reservation	**Wind River Reservation**	Wind River (1993-2003)		Wind River Reservation	2004-2006					
Bighorn National Forest	**Shell Creek**	Mill Creek (1989-2003)								
	Burgess Junction	Burgess Junction (1993-2003)								
	Buffalo	SchoolHouse (1989-2003)		Middle Fork Campground	2002-2004	6	0.99	0.99	-	-
	Ten Sleep Canyon			MiddleTensleepCanyon	2001-2003					
				LowerTensleepCanyon	2001-2005					
				UpperTensleepCanyon	2001-2005					

* Pearson Correlation Coefficients between specific HOBO station and a site corresponding RAWS or WYDOT station. PCC range from -1.0 to 1.0. A 1.0 correlation is the highest compatibility. (-) coefficients are not significant

Medicine Bow National Forest:

1. Siera Madre Mts
This area does not have any long-term meteorological stations in the region but two HOBOs were placed there in 2004 so we will analyze the 2004 and 20005 data in relation to other HOBOs in the Medicine Bow NF.

2. Laramie Peak East
At the Laramie Peak East study area, both HOBO stations correlated well with Esterbrook RAWS in mean temperature and relative humidity with coefficients over 0.90 (Table 7). Correlations with HOBO data were weaker for 50% and 25% of days, although all coefficients are above 0.60. The Esterbrook Road North HOBO data correlated with the Esterbrook RAWS data where greater than 25% of day was suitable for infection with a coefficient of 0.82 (Table 4).

3. Laramie Peak West
There are no HOBO stations at this location but the Casper Mt RAWS station can provide good long-term data. This data are presented in the results section

4. Medicine Bow Mts-North
HOBO units were placed at Centennial Ridge and at Arlington in 2004 and correlations will be performed between Saw Mill Park RAWS and Arlington WYDOT.

5. Medicine Bow Mts- South
A HOBO unit was placed at Centennial Ridge in 2004 and correlations will be performed between Saw Mill Park RAWS.

6. Pole Mt
Four HOBO stations in placed from east to west across Pole Mt were correlated to two long-term data sources, Vedauwoo WYDOT station and Pumpkin Vine WYDOT station. Vedauwoo was within two to 10 miles of the HOBO stations and correlated better with all HOBO stations in temperature than Pumpkin Vine station that was on Rt 287 over 10 miles away (Table 7). All relative humidity correlation coefficients were above 0.80 and most were above 0.90 for both WYDOT stations. Overall, Vedauwoo correlated better with the HOBO stations for 25% days suitable for rust infection, although Pilot Hill North had a coefficient of 0.95 with Pumpkin Vine. The variable 50% of days suitable for rust infection correlated well with both sites (>0.90) at the Pilot Hill North and South HOBO stations (Table 7). The Vedauwoo West and East HOBO stations did not correlate as well with either WYDOT station, although Vedauwoo East had a coefficient of 0.70 with the Vedauwoo WYDOT station (Table 7).

Wind River Reservation
The one HOBO station located on the east front of the Wind River Mts on the reservations will be correlated with the RAWS station located approximately 4 miles farther into the mountains.

Shoshone National Forest

1. Dubois

In the Dubois study area, the Horse Creek Basin HOBO station correlated well with the Elkhorn RAWS. Mean temperature, mean relative humidity, and the time greater than 50% of hours suitable for rust infection all had coefficients over 0.75 (Table 3). The 25% of day also correlated well, with a coefficient of 0.74 (Table 7). Two HOBO stations other stations in this study area were missing data at the time this report was written, and will be correlated with the Elkhorn RAWS in the future.

2. Cody

In the Cody area of Wyoming, correlations between HOBO stations and Crandall RAWS were not very high. These Pearson Correlation Coefficients were not sufficient to interpolate data from local, short-term stations to longer time intervals. Temperature and relative humidity all correlated above 0.90, but when data was narrowed down to specific suitable infection requirements, the correlations were not significant (Table 7).

Big Horn National Forest

1. Tensleep

The Tensleep study area was located in the Bighorn Mountains of northern Wyoming. Three HOBO stations in that area correlated with a long-term meteorological data source in the area. These stations were not correlated at the time this report was written, and will be correlated in the future. We did not have white pine blister rust incidence or severity data to compare with meteorological data at this time.

2. Buffalo

The Buffalo study area was located in the Bighorn Mountains of northern Wyoming. One HOBO station at the Middle Fork Campground was correlated with the School House RAWS station. The in correlations were good for average temperature and relative humidity but very poor with the 25% and 50% days. We did not have white pine blister rust incidence or severity data to compare with meteorological data at this time.

3. Burgess Junction

There are no HOBO stations here and the RAWS station could help explain the rust impact in the region but the data collected by Forest Health Management did not include canker size so there is no reasonable way to utilize the meteorological data from this site.

4. Shell Creek

This data will be analyzed and related to Jim Blodgett's survey data

Bureau of Land Management:

1. Shirley Mts

Two HOBOs were placed on the north and west slope of the Shirley Mts in 2004. We hope to correlate this data with the WYDOT station at Pathfinder Hill. This RAWS station is not a very good long-**term station since it is lower in elevation and some distance from the Shirley Mts.**

2. Green Mts

The HOBO at the Green Mts is at the bottom of the north slopes of the mountain range. We placed the machine there in 2004 and we will correlate the data with RAWS station at Camp Creek. The Camp Creek station was established in 1997 so it basically has recorded the drought that has occurred in that area.

Table 8. Colorado Meteorological Data Sources and Pearson Correlation Coefficients

Roosevelt National Forest	Northern Front Range	Red Feather (1985-2003)		Cherokee Park North	2001-2006	10	0.99	0.87	0.74	0.79
				Sheep Creek	2001-2006	10	0.99	0.88	0.38	0.56
				Prairie Divide	2001-2006	10	0.99	0.9	0.86	0.68
				Crystal Lakes	2001-2006	10	0.99	0.89	0.54	0.49
San Isabel National Forest	Upper Arkansas	Taylor Park (1988-2003)								
				Taylor Gulch/Garfield	2001-2006	8	0.99	0.99	0.84	0.86
		Red Deer (1985-2003)		Cottonwood Pass	2001-2004	10	0.99	0.97	0.91	0.83
				Mount Princeton	2001-2006	10	0.99	0.98	0.89	0.61
				Mount Massive Lakes East	2001-2006	10	0.99	0.95	0.39	0.74
				Lost Canyon Road/Quail Mt.	2001-2006	10	0.99	0.97	0.66	0.92
	Wet Mountains	Willis Creek (1997 - 2003)		Wet Mountains #1	2004-2006					
				Wet Mountains #2	2004-2006					
	Mosca Pass	Sand Dunes (2004)		East Mosca Pass (CSU)	2004-2006					
				North Mosca Pass (CSU)	2004-2006					
				Medano Pass (CSU)	2004-2006					
				Mosca Pass (CSU)	2004-2006					
				East Mosca Pass (RMRS)**	2004-2006					
				West Mosca Pass (RMRS)**	2004-2006					
Pike National Forest	South Park	Lake George (1991-2003)		Fourmile Creek/Fairplay	2001-2006	10	0.99	0.94	0.63	0.86
				Michigan Hill/Jefferson	2001-2006	10	0.98	0.9	0.6	0.01
				RedHill Pass	2001-2006	10	0.99	0.95	0.35	0.6
				Dicks Peak	2002-2003	7	0.99	0.96	0.75	0.55
				Currant Creek Pass	2002-2006	7	0.99	0.96	0.67	0.86
	South Park	Soda Creek (1987-2003)		Fourmile Creek/Fairplay	2001-2006	10	0.99	0.98	0.41	0.86
				Michigan Hill/Jefferson	2001-2006	10	0.99	0.93	0.22	0.76
				RedHill Pass	2001-2006	10	0.99	0.94	0.21	0.63
				Dicks Peak	2002-2006	7	0.99	0.95	-	0.69
				Currant Creek Pass	2002-2006	7	0.99	0.94	-	0.7
	South Park	Bailey (1995-2003)		Fourmile Creek/Fairplay	2001-2006	10	0.99	0.79	0.11	0.28
				Michigan Hill/Jefferson	2001-2006	10	0.99	0.88	0.02	0.4
				RedHill Pass	2001-2006	10	0.99	0.88	0.3	0.73
				Dicks Peak	2002-2006	7	0.98	0.92	0.22	0.72
				Currant Creek Pass	2002-2006	7	0.98	0.93	0.15	0.6
Rio Grande National Forest	Rio Grande	Blue Park (1993-2003)		Upper Agua Ramone	2001-2006	10	0.99	0.92	0.56	0.83
				Lower Agua Ramone	2001-2006	10	0.99	0.93	0.88	0.62
				Demi John Peak 1	2001-2006	10	0.99	0.94	0.56	0.79
				Bennet Peak 1	2001-2006	10	0.99	0.94	0.66	0.92

**Contact: Anna Shoettle, Rocky Mountain Research Station Fort Collins

* Pearson Correlation Coefficients between specific HOBO station and a site corresponding RAWS or WYDOT station. PCC ranges from -1.0 to 1.0. A 1.0 correlation is the highest compatibility.

Colorado:
Several study areas in Colorado had fairly high and consistent Pearson Correlation Coefficients between the long and short-term weather stations. Some of the HOBO stations had extremely low, even negative, Pearson Correlation Coefficients with the long term data sources

Northern Front Range:
In the Northern Front Range study area, HOBO station temperature and relative humidity correlated highly with the Red Feather RAWS (Table 8). All HOBO stations correlated well for the temperature variable and all were over 0.85 with respect to relative humidity. Cherokee Park and Prairie Divide HOBO stations both correlated over 0.70 for suitable time greater than 25% (Table 8). Correlation coefficients were slightly lower for suitable time greater than 50% but both HOBO stations had correlation coefficients greater than 0.65.

Upper Arkansas Valley:
In the Upper Arkansas study area, all HOBO stations correlated highly with Taylor Park or Red Deer RAWS. With the exception of one variable and station, all correlation coefficients were higher than 0.60, with the majority of correlations higher than 0.80 (Table 8).

South Park:
In the South Park, Colorado study area, five HOBO stations were compared to three different long-term meteorological data sources: Lake George RAWS, Soda Creek RAWS, and Bailey RAWS. Four mile Creek and Michigan Hill HOBO stations correlated above 0.60 with the Lake George RAWS in the amount of time with suitable periods (Table 8). The amount of time greater than 25% suitable for rust infection variable did not have good correlation between the South Park HOBO stations and the Soda Creek or Bailey RAWS. All correlation coefficients were under 0.41 and some are negative numbers (Table 8). Soda Creek had the most consistently high correlations with HOBO stations when comparing amount of time greater than 50% suitable for rust infection (all Pearson Correlation Coefficients were above 0.63). Soda Creek and Bailey RAWS stations are located north of South Park on the other side of mountain ranges so we would not expect great correlations. Lake George is the closest in the sense of being located on the south east side of South Park

Rio Grande

In the Rio Grande study area, all HOBO stations correlated highly (>0.90) with the Blue Park RAWS, for temperature and relative humidity variables. Both suitable infection time period variables had fairly high correlations. Four correlations coefficients were above 0.80 while five more were above 0.55 (Table 8). The HOBO stations in the Rio Grande study area correlated highly and consistently with the.

Mosca Pass and Wet Mountains Study Areas, Colorado
The Mosca Pass/Great Sand Dunes area in southern Colorado recently had four HOBO stations added to the area in 2003 and 2004 and two more were added in 2004 through the Ft. Collins Rocky Mountain Research Station (Table 8). Two HOBO stations were added to the Wet Mountains area in 2005, and these stations will be correlated with the Willis Creek RAWS, which had been collecting data since 1997. White pine blister rust was discovered on five needle

pines and *Ribes* species in these two areas in 2003. The Sand Dunes RAWS has only been collecting meteorological data since 2004, therefore comparable months (N) between RAWS and HOBO stations were too low to make conclusions.

Objective 2. Determine if differences in meteorological conditions occur among white pine blister rust study sites in Colorado and Wyoming.

Based on data analysis of long-term data from RAWS stations, the number of months out of 10 years with 5% and 10% of the days suitable for infection by the rust varied from 5 to 32 months. All RAWS stations were selected from areas that had rust nearby (Fig. 1 and 2). Five percent of the days suitable for infection is approximately 1.5 and 10 % of the days are 3 days with at least 25% of time suitable for infection. When at least one-quarter of these days were suitable for infection, approximately six hours of time was suitable. According to the literature, this was sufficient time for infection to occur. Colorado has many more months with suitable days for infection than Wyoming stations.

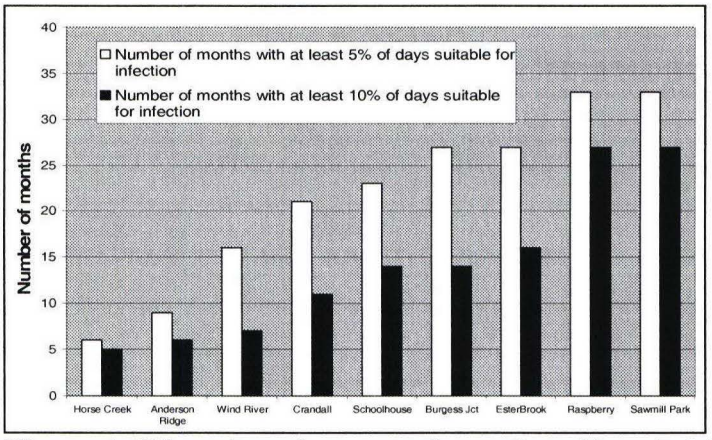

Figure 1. Wyoming: Amount of months with suitable infection periods >5% of days based on RAWS stations with 10 years of data.

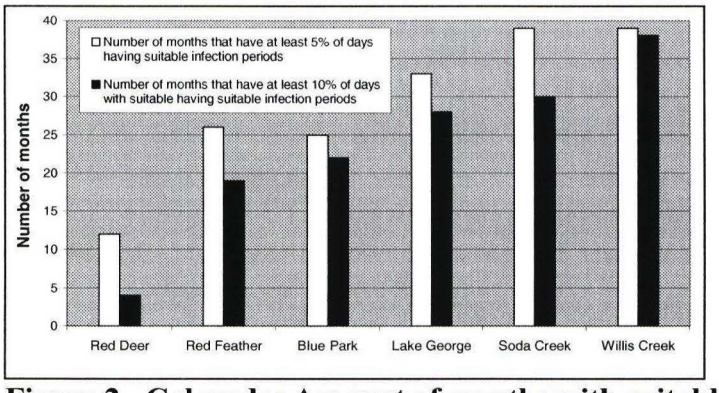

Figure 2. Colorado: Amount of months with suitable infection periods >5% of days based on RAWS stations with 10 years of data.

In Wyoming, Horse Creek had the lowest number of months with suitable periods. Sawmill Park had the highest number of months. Sites with the highest number of months, out of 10 years * 4 months (April, May, July, or August) = 40 months, ranged from 30 to 35 months (Fig. 1).

In Colorado, the number of suitable periods was generally higher than those in Wyoming, with almost every month having at least 1.5 days with at least 6 hours of time suitable for rust infection (Fig. 2). The Red Deer study area had the lowest number, while Willis Creek and Soda Creek had the highest amount of time.

After months were tallied up, Colorado sites, in general, had more periods suitable for rust to occur than Wyoming sites (Fig. 1 and 2). All sites in Wyoming had rust present, and incidences varied at study sites (Kearns 2005). In preliminary results using temperature, time, and relative humidity variables, we conclude Colorado had more time suitable for infection than Wyoming and therefore may be as, if not more, vulnerable to infection of white pine blister rust on five needle pines and *Ribes* species.

We used temperature and relative humidity data by month and year at each site to create a pressure index for white pine blister rust at each site ranging from 0.0 to 2.0 (Fig. 3 and 4). Spring (May and June) and fall (August and September) months of each year were given a value from 0.0 to 2.0 based on the month's percentage of time with suitable infection periods. If the month had no time with suitable infection periods it was given a 0. If the month had greater than 0% but less than 10% of time with suitable infection periods it was given a 1.0. If the month had greater than 10% of time with suitable infection periods it was given a 2.0. Values were added and averaged out to a value between 0 and 2. Sites with a high-pressure number have the most episodes of suitable conditions and are more conducive for rust infection (Fig. 3 and 4).

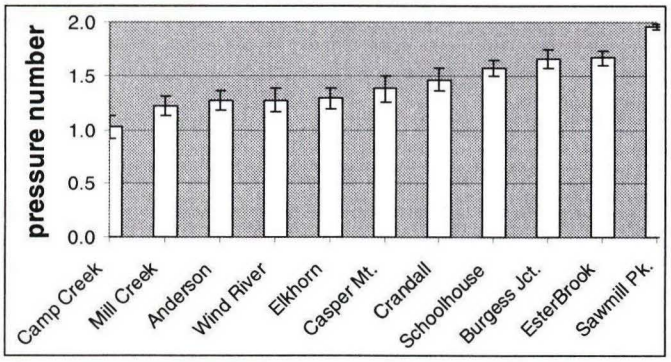

Fig. 3. Pressure index for white pine blister rust based on Wyoming RAWS.

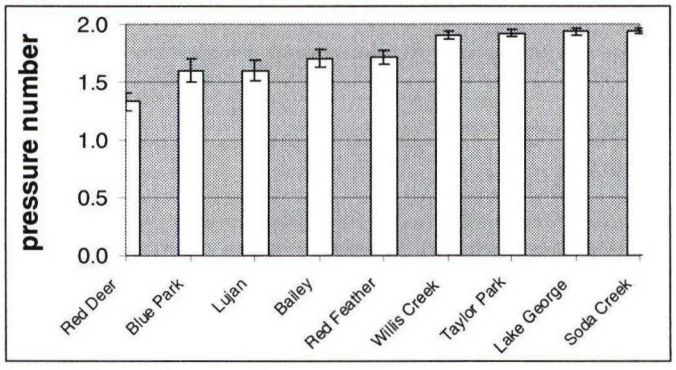

Figure 4. Pressure index for white pine blister rust based on Colorado RAWS.

The RAWS weather station data were used to build the pressure indices with meteorological measurements taken every half hour throughout the year. All sites in Wyoming had at least 10 years of high quality data, except for Casper Mountain and Camp Creek RAWS. These stations began data collection in 1995 and 1997, respectively. The significant differences in pressure indices between study sites in Wyoming were impressive but all these sites had trees with rust infections (Fig 3). Camp Creek has the lowest pressure number, although there were limited data available for this study area. When relative humidity and variables were compared across sites, Camp Creek was generally the driest (data not shown). Sawmill Park again has the highest pressure number and was the site with the most time for potential suitable infection periods to occur (Fig. 3).

In Colorado, there are three main groups of study sites with similar pressure indices (Fig. 4). Red Deer sites have the lowest pressure numbers, while Blue Park, Lujan, Bailey and Red Feather study sites all fall around the pressure number 1.5. The third group, comprised of Willis Creek, Taylor Park, Lake George, and Soda Creek are significantly higher in pressure value than the rest of the Colorado study sites and are all in the 1.0 – 2.0 range (Fig. 4).

Discussion

Objective 1. Determine if long term, regional meteorological data sources have comparable data with temporary meteorological stations placed in white pine stands.

The majority of data on average temperature and RH from long term RAWS and WYDOT meteorological stations throughout Wyoming and Colorado correlate well with the HOBO stations placed directly in limber pine stands throughout the states. The correlations of the 25% and 50% of the days with suitable conditions are somewhat well correlated. Wyoming study sites Laramie Peak East, Wind River and Pole Mountain all had consistently high correlations (>0.60). The Bighorn and Cody study sites had extremely low correlations with respect to the suitable time period variables. These correlation coefficients were less than 0.50 and some were even negative. Low coefficients are not sufficient to interpolate data from local, short-term stations to longer time intervals. The long-term data sources from these study sites should not be interpolated to white pine stand meteorological conditions in Wyoming.

Some study areas in Colorado had fairly high and consistent correlations between HOBO stations and long-term data sources. At the Northern Front Range study site, two HOBO stations were consistently above 0.60 for all variables correlated (Cherokee Park North and Prairie Divide HOBO stations). At the Upper Arkansas study site, three of four HOBO stations correlated with the Red Deer RAWS above 0.60 (Cottonwood Pass, Mount Princeton, Lost Canyon Road). The Rio Grande study site also had consistently high correlations, most over 0.60 for each HOBO station and Blue Park RAWS correlation. We consider the correlations above 0.60 between HOBO stations and long term, regional meteorological data sources (usually RAWS) sufficient for data interpolation to white pine habitats throughout Colorado and Wyoming.

There were extremely low or negative correlations at some study sites in Colorado. In the South Park study site, comparing HOBO stations with Soda Creek RAWS resulted in some extremely low or nonsignificant correlations. These same HOBO stations did not correlate well with Bailey RAWS in the same study site (0.22 and 0.15 for suitable period variables). These Pearson Correlation Coefficients are not sufficient to interpolate data from regional, long-term data sources to white pine stands throughout Colorado. However, Dicks Peak and Current Creek Pass HOBO stations both correlated above 0.65 for the same suitable period variables when using the Lake George RAWS. By using three long-term stations to correlate to the HOBO stations in the South Park study site, we found the proper long-term stations to interpolate meteorological data to specific white pine habitats in the area. Most of this variation in correlations can probably be explained by elevation and distance between the long and short term stations.

Objective 2. Determine if differences in meteorological conditions occur among white pine blister rust study sites in Colorado and Wyoming.

Observable differences between times suitable for rust infection in white pine blister rust study sites existed in Wyoming and Colorado. All Wyoming sites had at least 5 months (over ten years) with 1.5 or 3.0 days where suitable conditions for rust infection occurred. These conditions occurred at least 6 hours in each of these days, which is sufficient time for infection to occur. The least time available for infection occurred at the Horse Creek site, where incidence of white pine blister rust was 18.6% (Kearns 2005). Wind River Reservation study site had more time available for infection and a higher incidence, 55.9% (Kearns 2005). Wind River and Elkhorn occurred as similar pressure numbers in our pressure index (Fig. 3). Laramie Peak East study site (Esterbrook RAWS) was one of the sites in Wyoming with the most conducive time available for rust infection, and has a study site white pine blister rust incidence of 27.2%. Esterbrook occurs as the second highest pressure number of our pressure index (Fig. 3). Sawmill Park, in the Medicine Bow Mt South study site, had a low incidence of 0.9% (Kearns 2005). Sawmill Park is also the highest pressure number of our pressure indices (Fig. 3), significantly higher than every other site in Wyoming, meaning it has the greatest amount of time with suitable rust conditions. We believe that aside from local meteorological conditions like temperature and humidity, other important site variables for rust to occur include wind and air currents and the amount of time the rust spores have been present in that area on either host. For the Medicine Bow Mt South region, *C. ribicola* spores may not have traveled via air currents to the site until recently. The local and regional meteorological conditions in the Medicine Bow Mt

South (Sawmill Park RAWS) white pine blister rust study site are extremely suitable for rust infection to occur and disperse.

In Colorado, the number of months with at least 1.5 or 3.0 days where suitable conditions for rust infection occur was generally higher than Wyoming. All study sites, with the exception of Red Deer, had at least 15 or 20 months suitable for infection (Fig. 2). Therefore, at least half the months had 1.5 or 3.0 days suitable for rust to occur. There are no incidence data for Red Deer or many of the Colorado white pine blister rust study sites.

Incidence on the Northern Front Range study site was 4.1% (Kearns 2005). The variables from area meteorological stations, Red Feather RAWS and corresponding HOBO stations, puts Red Feather above 1.5 on our pressure index (Fig. 4). The majority of study sites in Colorado are at or above 1.5, with the exception of Red Deer. One site in Colorado, Willis Creek, is in the Wet Mountains area and has a higher pressure number than Red Feather. White pine blister rust was recently found in this area, although we do not have incidence data. Suitable meteorological conditions occur more frequently at sites with higher proportions of months in this index, therefore we assume that these areas are more suitable for rust to occur, disperse, reproduce and infect five needle pines.

Future work on these two objectives will attempt to relate duration of infestation, incidence, and relative number of infection episodes over the duration of the infestation with the pressure indices developed in this study.

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